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SUBJECT: Progress Report for the Period 1 October 1965 through
31 March 1966 - NSG 107-61.

Progress for this period is reported in the following categories:

1. Development of a spatially continuous remote touch sensor -
T. G. Strickler.
2. Simulation study of supervisory control of a manipulator
using entirely computer-simulated task for the human
operator - S. G. McCandlish.
3. Simulation study of supervisory control of a manipulator
using an actual manipulator and mechanical environment -
T. D. Rarich, J. D. Barber, W. L. Verplank, D. E. Whitney.
4. Optimal control norms for human operators in preview
control tasks - P. A. Hardin, R. D. Roland, B. F. Fabis,
D. C. Miller.
5. Remote touch sensing - auditory feedback - W. F. Klepser Jr.
6. Remote touch sensing - tactile feedback - R. B. Tanner.

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1. Development of a spatially continuous remote touch sensor - T. G. Strickler.

The optical deformation touch sensor described in the previous progress report has been fabricated and interfaced with the AMF-8 manipulator and a closed circuit TV system for experimental evaluation.¹

2. Simulation study of supervisory control of a manipulator using entirely computer-simulated task for the human operator - S. G. McCandlish. (This project is being jointly supported by the U.S. Air Force)

Data taking on this task, described in detail in the previous progress report, has been completed.² Independent variables were: 1) dynamic lag of manipulator, 2) transmission delay, 3) intermittency of vision, 4) use of automatic subroutines in lieu of continuous manual control for certain portions of the task. Dependent variables were: 1) task completion time, 2) number of discrete open loop commands or actions taken by the human operator, 3) energy used (assuming all acceleration energy lost).

Results support earlier work on this project which suggests that transmission delay does not make remote manipulation impossible, and that intermittent visual feedback and the lack of rate information in the display (the operator must infer rate by comparing successive static frames) does not necessarily impair control performance. Thus a low-capacity feedback channel may be sufficient for manipulation tasks.

Results with the human operator in the supervisory mode (calling automatic subroutines for certain portions of the task) show that this mode is superior to continuous manual control under long time delay and exacting task tolerances.

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1. Strickler, T. G., Design of an Optical Touch Sensing System for a Remote Manipulator, S.M. Thesis, Mech. Engr., June 1966.
 2. McCandlish, S. G., A Computer Simulation Experiment of Supervisory Control of a Remote Manipulation, S.M. Thesis, Mech. Engr., June 1966.

of both human and computer to manipulator and manipulated objects and to each other).

4. Optimal control norms for human operators in preview control tasks -

P.A. Hardin, R.D. Roland, B.F. Fabis, D.C. Miller.

Several programs have been written which compute optimal thrusting control of a two-dimensional second order dynamic process for a given initial state, a given terminal state, a given obstacle space intervening, and a given performance criterion. The dynamic programming algorithm has served as the basis for these numerical simulations. Emphasis is being placed upon a means to iterate the solution using a finer and finer grid reticulation in a successively restricted region near optimal. This work is to be used eventually to study "self pacing" control by human operators in situations where they may "speed up on straightaways and slow down on curves" (i.e. the input is spatial rather than temporal) and may preview the course ahead to a limited extent.

Some initial experiments were run by Sheridan, Roland and Fabis⁴ using a simple preview control task on a computer display. A second order system (a dot on the display) moved vertically at constant rate while the operator controlled lateral acceleration. The task was to minimize a given penalty function of acceleration and error (with respect to two randomly spaced "target dots" along the path. Results indicated that performance deviated from optimal mostly in terms of an increment of response variability or noise. Experiments are being planned by Miller using analog computer simulated terminal state control tasks (like rendezvous) for which optimal solutions can be generated analytically.

4. Sheridan, T.B., Fabis, B.F., and Roland, R.D., "Preview Control Behavior and Optimal Control Norms," Proc. MIT/NASA Working Conference on Manual Control, NASA, Washington, D.C., 1966.

5. Remote touch sensing - auditory feedback - W.F. Klepser Jr.

Several techniques for detecting and presenting to the operator the sounds generated by the remote hand of a manipulator making contact with its environment have been tried and tentatively evaluated.⁵ The objective has been to provide the operator with useful feedback he can not get through visual observation. The methods used were:

1. A single ordinary microphone mounted on the remote hand relaying its signals to the operator's earphones.
2. A single contact microphone integral with one of the remote fingers relaying the sound to earphones.
3. Two ordinary microphones mounted on the remote hand - each connected separately to one of the operator's earphones to give binaural coverage.

Although the experimental trials have not been as extensive as one would wish, several conclusions have been drawn.

1. If the manipulator and task are such as to provide good force feedback the addition of auditory cues is unlikely to lead to improvement in performance.
2. At low force feedback levels (as with very light objects) auditory cues make it possible to perform many tasks when the operator cannot see, but the time required is much longer than with vision.
3. Binaural cues make it significantly faster and easier to determine where on the hand contact takes place.
4. Ordinary microphones, unlike contact microphones, are sensitive to extraneous noises such as those of the manipulator mechanism, but they make it possible to use flexible whiskers or antennae for rapid searching and gross orientation of the remote hand.

5. Klepser, W., An Investigation of some Non-Visual Aids to Remote Manipulation, B.S. Thesis, Mech. Engr., May 1966.

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6. Remote touch sensing - tactile feedback - R. B. Tanner.

A system for providing the operator of an AMF mechanical remote manipulator with an indication of the pressure applied at a number of discrete points on the remote fingers has been designed and built. Pressure is sensed by conducting rubber pads the electrical resistance of which decreases with compression. A decrease in resistance of a pad permits a proportionately greater current to flow through a circuit of which part is the skin of the operator's finger at a point corresponding to the pads location on the remote hand. The circuits are designed so that with no pressure the operator cannot detect the electrical stimulation and with maximum pressure it is not painful. Principal difficulties have been encountered in

1. making reliable and simple electrodes
2. obtaining a reasonably fine two point discrimination. The electrical stimulation tends to be perceived as diffuse over a wide area.

Sufficient progress has been made to begin tests of the apparatus with several touch spots on each of the two fingers.